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Venkatraman et al.

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(54) BUILDING A CUSTOM SOFTWARE ENVIRONMENT INCLUDING PRE-LOADED CLASSES

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(52) **U.S. Cl.** **717/166**; 717/108; 717/118; 717/147; 717/148; 717/153; 717/165; 717/167

(58) **Field of Search** 717/166, 106, 717/118, 140, 147, 148, 152, 153, 164, 165

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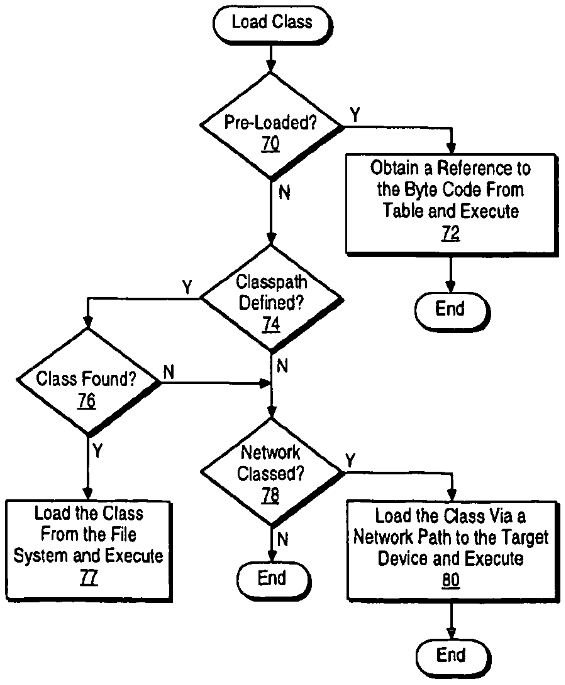
Assistant Examiner—Ted T. Vo

(57) **ABSTRACT**

A system for creating a custom environment for executing application programs in a target device. The system broadens the applicability of software environments like Java by providing custom pre-loaded classes for application programs and by customizing the procedures for class loading to the available resources in the target device. The system includes tools for generating a pre-load class list that specifies a set of classes needed to support the application program. The tools build the custom environment including a set of code for a virtual machine and a set of code for each of a set of pre-loaded classes specified in the pre-load class list. The virtual machine loads classes from the pre-loaded classes, a file system class library, and/or a networked class library using widely available network protocols.

15 Claims, 5 Drawing Sheets


Load Class
Pre-Loaded? 70
Y
N
Obtain a Reference to the Byte Code From Table and Execute 72
End
Classpath Defined? 74
Y
N
Class Found? 76
N
Y
Network Classed? 78
Y
N
Load the Class From the File System and Execute 77
End
Load the Class Via a Network Path to the Target Device and Execute 80
End

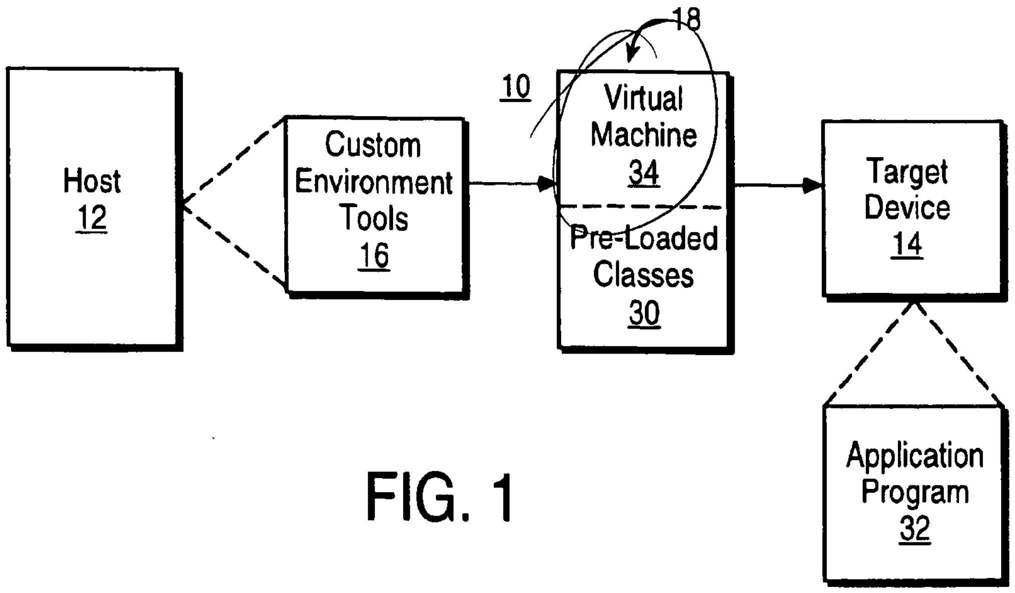

18
10
Host 12
Custom Environment Tools 16
Virtual Machine 34
Pre-Loaded Classes 30
Target Device 14
Application Program 32

FIG. 1

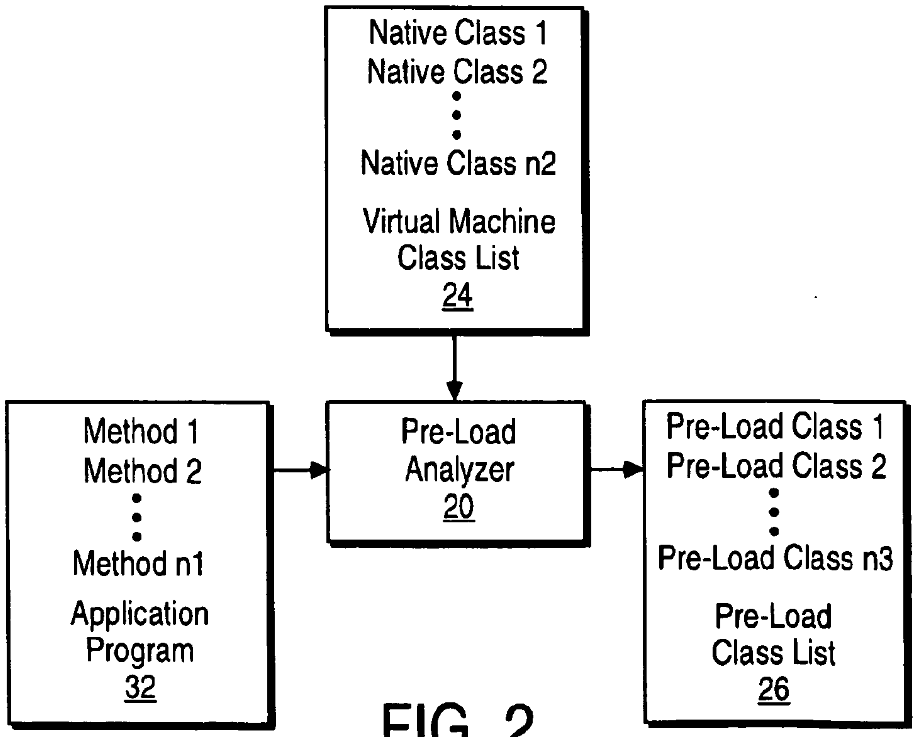

Native Class 1
Native Class 2
Native Class n2
Virtual Machine Class List 24
Method 1
Method 2
Method n1
Application Program 32
Pre-Load Analyzer 20
Pre-Load Class 1
Pre-Load Class 2
Pre-Load Class n3
Pre-Load Class List 26

FIG. 2

FIG. 3

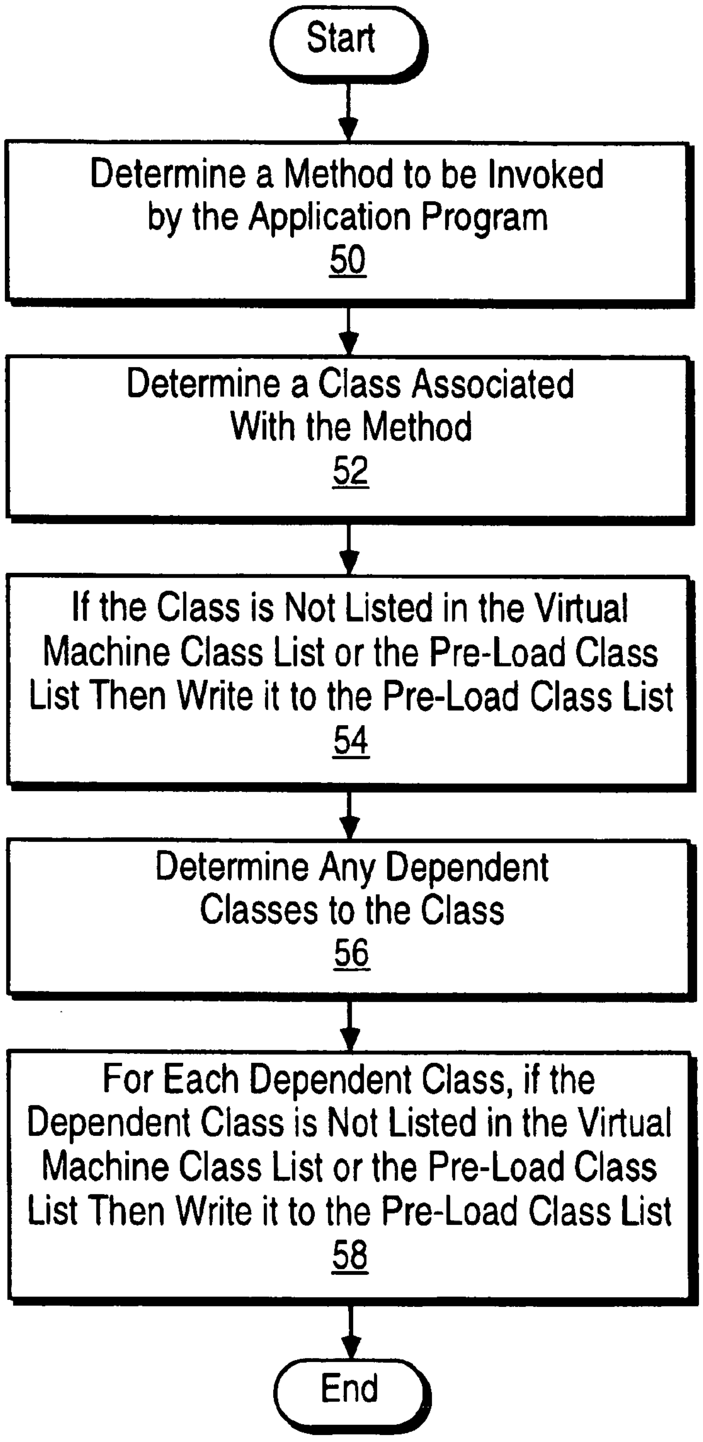
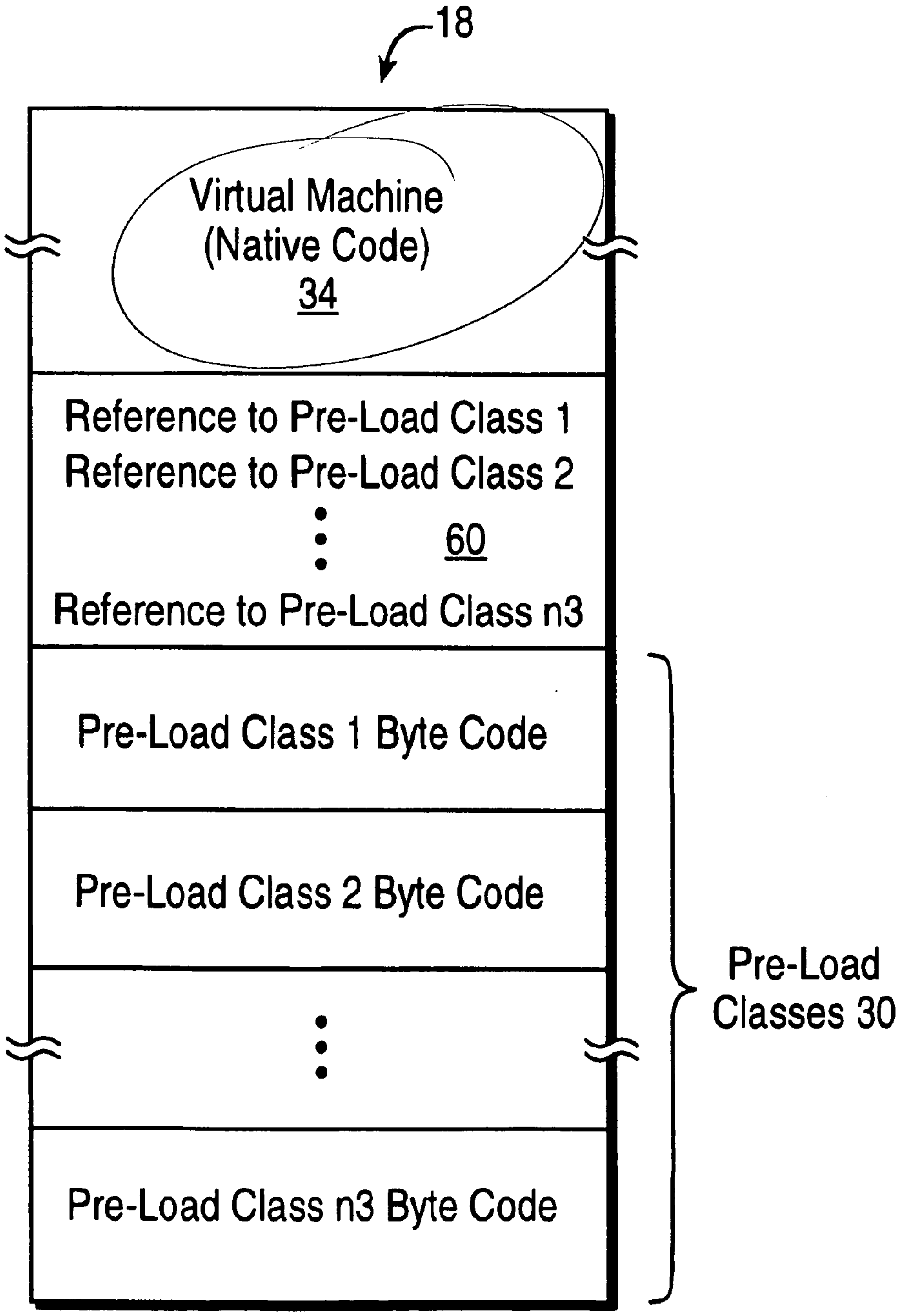

Start
Determine a Method to be Invoked by the Application Program 50
Determine a Class Associated With the Method 52
If the Class is Not Listed in the Virtual Machine Class List or the Pre-Load Class List Then Write it to the Pre-Load Class List 54
Determine Any Dependent Classes to the Class 56
For Each Dependent Class, if the Dependent Class is Not Listed in the Virtual Machine Class List or the Pre-Load Class List Then Write it to the Pre-Load Class List 58
End

FIG. 4


18
Virtual Machine (Native Code) 34
Reference to Pre-Load Class 1
Reference to Pre-Load Class 2
60
Reference to Pre-Load Class n3
Pre-Load Class 1 Byte Code
Pre-Load Class 2 Byte Code
Pre-Load Class n3 Byte Code
Pre-Load Classes 30

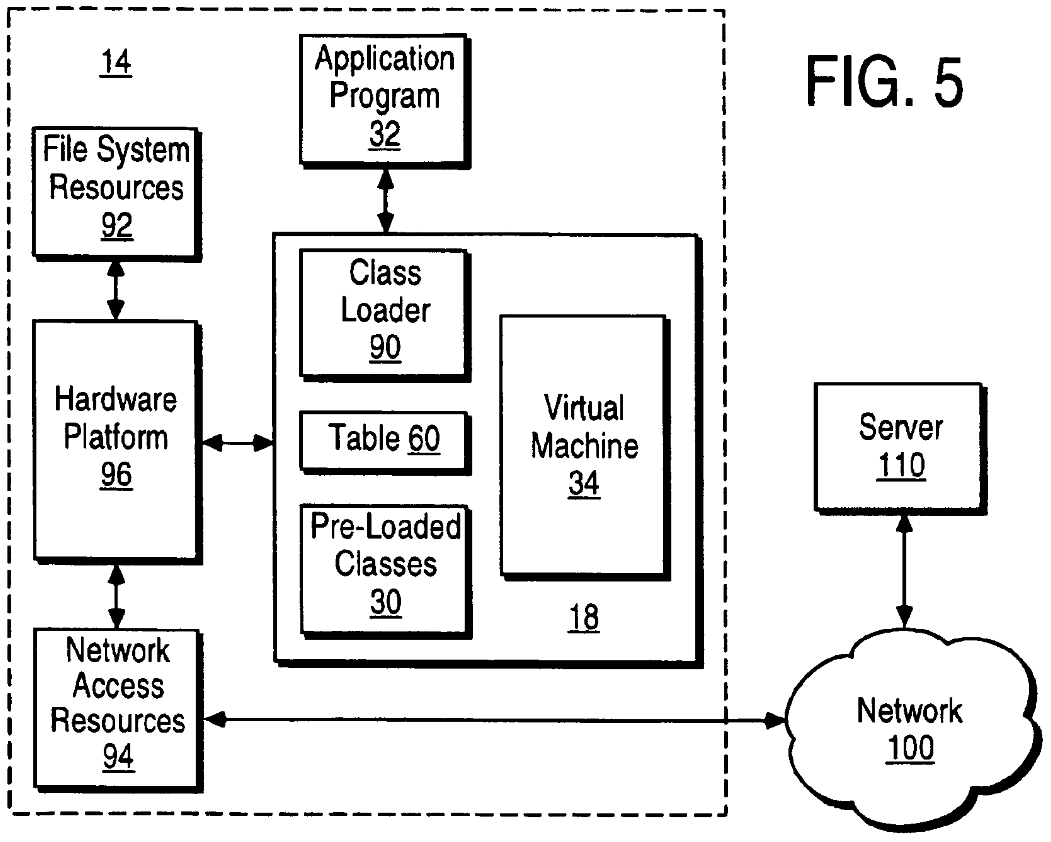
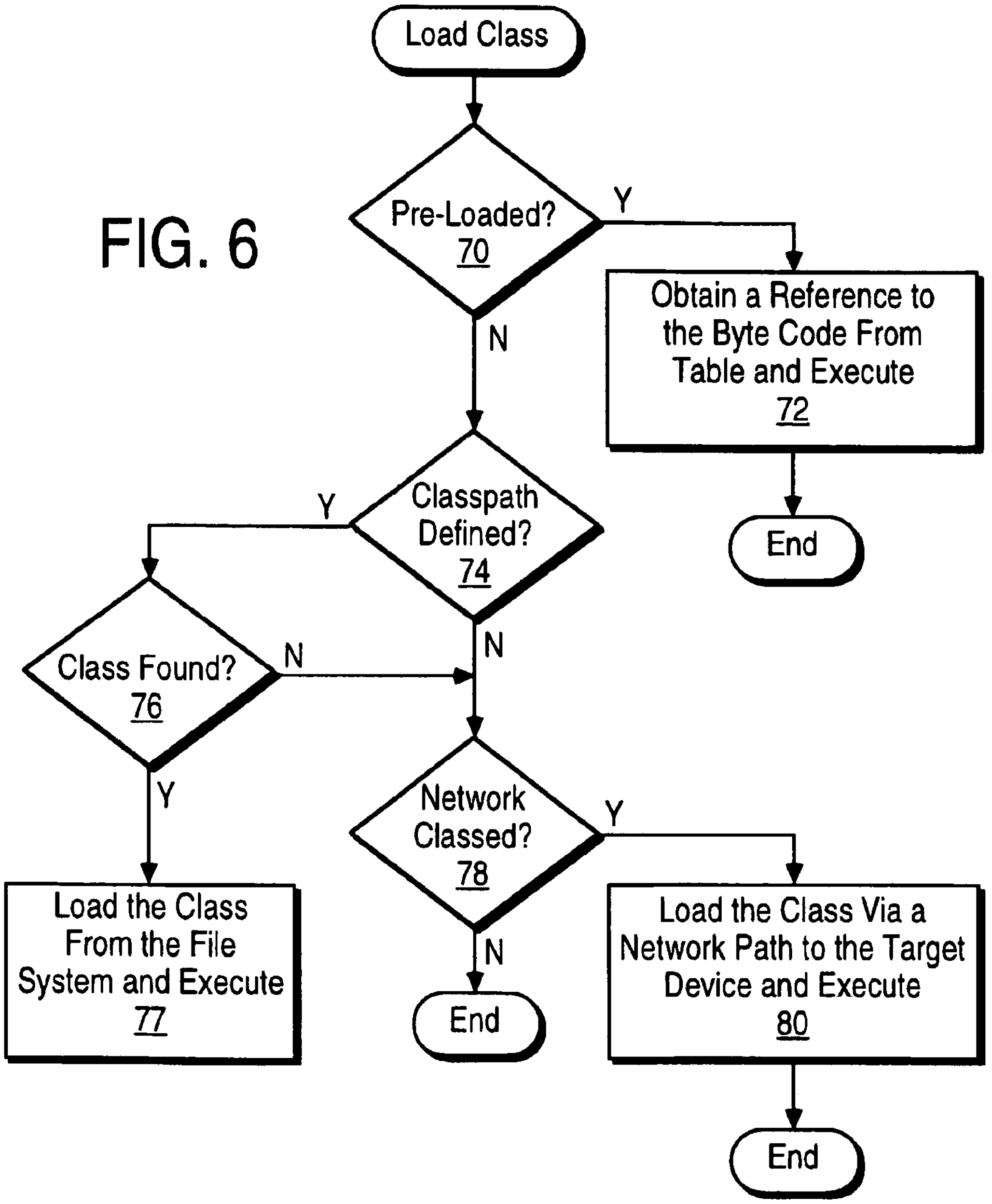

14
Application Program 32
File System Resources 92
Class Loader 90
Hardware Platform 96
Table 60
Virtual Machine 34
Pre-Loaded Classes 30
18
Network Access Resources 94
Server 110
Network 100

FIG. 5

FIG. 6


Load Class
Pre-Loaded? 70
Y
Obtain a Reference to the Byte Code From Table and Execute 72
End
N
Classpath Defined? 74
Y
Class Found? 76
N
N
Y
Load the Class From the File System and Execute 77
Network Classed? 78
Y
Load the Class Via a Network Path to the Target Device and Execute 80
N
End
End

BUILDING A CUSTOM SOFTWARE ENVIRONMENT INCLUDING PRE-LOADED CLASSES

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention pertains to the field of software systems. More particularly, this invention relates to building a custom software environment including pre-loaded classes.

2. Art Background

Computer systems and devices having embedded processing resources typically conform to one of a variety of differing architectures. Each architecture is usually defined by a particular instruction set, hardware register set, and memory arrangement, etc. An architecture may also be referred to as a hardware platform for software execution. Software such as application programs which are written or compiled to be executed on a particular hardware platform may be referred to as native code. An application program in the native code of a particular hardware platform usually does not run on other non compatible hardware platforms.

Some prior software environments enable application programs to execute on a variety of differing hardware platforms. Typically, such a software environment provides a set of predefined services that enable an application program to interact with the hardware and operating system of a particular hardware platform. The predefined services are usually specified in terms of application programming interfaces (APIs) which an application program uses to invoke the predefined services. Such a software environment is commonly implemented in an object-oriented programming language in which the predefined services are implemented as predefined classes.

One example of such a software environment is a Java virtual machine. Typically, a Java virtual machine for a particular hardware platform is an implementation of a set of predefined Java classes in native code. In addition, a Java virtual machine usually supports a set of predefined additional classes which may be referred to as class libraries. These class libraries are usually stored in a file system. These class libraries may also be stored on network based file systems which are accessible using network access features of the particular hardware platform. Typically, a Java virtual machine includes a class loader that loads classes from the class libraries as needed when executing a Java application program.

A software environment such as Java is usually specified in a "well-defined" software standard to which developers of virtual machines and application programs comply. Such a software standard usually specifies a set of APIs for the native classes which must be supported in an implementation of the software environment. Such a software standard also usually specifies a set of APIs for the class libraries which must be available in a local file system of the particular platform or network file system accessible by the particular platform.

Unfortunately, such well-defined software standards may limit the applicability of such a software environment. For example, such a software environment may have limited applicability to embedded systems which usually have limited resources in comparison to computer systems. Examples of embedded systems include telephones, audio and video equipment, home appliances, and computer peripherals.

For example, an embedded system may have little or no file system resources for storing the class libraries required by a well-defined standard. In addition an embedded system may have no network access or only sporadic or unreliable network access for loading class libraries required by a well-defined standard. Moreover, the costs of providing the file system and/or network access resources needed to support a well-defined standard may be prohibitively expensive for many embedded systems.

SUMMARY OF THE INVENTION

A system is disclosed for creating a custom environment for executing application programs in a target device. The system broadens the applicability of software environments like Java by providing custom pre-loaded classes for application programs and by customizing the procedures for class loading to the available resources in the target device. The system includes tools for generating a pre-load class list that specifies a set of classes needed to support the application program. The tools build the custom environment including a set of code for a virtual machine and a set of code for each of a set of pre-loaded classes specified in the pre-load class list. The virtual machine loads classes from the pre-loaded classes, a file system class library, and/or a networked class library using widely available network protocols.

Other features and advantages of the present invention will be apparent from the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is described with respect to particular exemplary embodiments thereof and reference is accordingly made to the drawings in which:

FIG. 1 illustrates a software development system including a set of tools for building a custom environment having pre-loaded classes;

FIG. 2 illustrates the functions of a pre-load analyzer of the custom environment tools;

FIG. 3 illustrates steps implemented on the pre-load analyzer for generating the pre-load class list;

FIG. 4 shows an example arrangement for the custom software environment;

FIG. 5 shows one embodiment of a target device which is an embedded system;

FIG. 6 shows steps implemented in a class loader of the custom software environment for loading a particular class during execution of the application program in the target device.

DETAILED DESCRIPTION

FIG. 1 illustrates a software development system **10**. The software development system **10** includes a set of custom environment tools **16**. The custom environment tools **16** enable the development of a custom software environment **18** which is customized to support an application program **32** which executes on a target device **14**. The custom software environment **18** is customized in response to the available resources in the target device **14** and the particular functions performed by the application program **32**.

The custom environment tools **16** enable a software developer for the target device **14** to assemble together only those classes that are needed to support a desired application. This minimizes the amount of hardware resources needed in the target device **14** and broadens the applicability of programming languages like Java to embedded systems.

In addition, the custom environment tools **16** enable a software developer for the target device **14** to customize the class loading performed by the software environment **18** to the particulars of the target device **14** and the application program **32**. The custom environment tools **16** provide, in one embodiment, the "write once run anywhere" capabilities of Java but with previously unavailable customization for target devices.

The application program **32** performs a set of predetermined functions in the target device **14** according to a particular application. The custom software environment **18** yielded by the custom environment tools **16** includes a virtual machine **34** which interprets instructions of the application program **32** and a set of pre-loaded classes **30** which are needed to support the application program **32**.

The custom software environment **18** is customized to a particular application of the target device **14** in that the native classes of the virtual machine **34** and the pre-loaded classes **30** include only those classes that are needed for execution of the application program **32**. This reduces the amount of class loading by the virtual machine **34** which would slow execution of the application program **32**.

In addition, the custom software environment **18** is customized to a particular application of the target device **14** in that the class loader in the virtual machine **34** enables a developer to specify class libraries from differing sources depending upon the available resources and nature of the target device **14**. For example, if the target device **14** has file system resources but no network access or sporadic network access then a developer may include all the necessary classes for the application program **32** in the pre-loaded classes **30** and/or in class libraries in the target device **14**. On the other hand, if the target device **14** has little or no file system resources but has network resources sufficient for the widely supported hyper-text transfer protocol (HTTP) protocol then a developer may include all the necessary classes for the application program **32** in the pre-loaded classes **30** and/or in class libraries on an HTTP server.

The target device **14** represents any device which may benefit from the advantages provided by the custom environment tools **16**. This may include devices with relatively little or no file system resources. The target device **14** may be an embedded system in which the application program **32** performs a set of relatively few functions in comparison to the functions performed in a computer system. Examples of embedded systems include telephones, audio and video equipment, home appliances, and computer peripherals.

The following description focuses on using the custom environment tools **16** to create the software environment **18** for the application program **32**. However, these techniques are readily adaptable to customize the software environment **18** to multiple application programs in the target device **14**.

FIG. **2** illustrates the functions of a pre-load analyzer **20** which is part of the custom environment tools **16**. The pre-load analyzer **20** is run on the host **12** when building the custom software environment **18** for execution of the application program **32** on the target device **14**. The pre-load analyzer **20** analyzes the application program **32** to determine which classes are needed for it to execute on the target device **14**. The pre-load analyzer **20** bases its analysis on a set of methods **1**-n**1** which are invoked by the application program **32**.

The pre-load analyzer **20** takes as input a virtual machine class list **24**. The virtual machine class list **24** specifies a set of native classes **1**-n**2** which are implemented in the virtual machine **34**. In one embodiment, the native classes **1**-n**2** are Java classes associated with hardware interaction or interaction with an operating system of the target device **14**.

The pre-load analyzer **20** takes as input a list of classes which are networked classes, if any, which are to be loaded from an HTTP server by the class loader of the virtual machine **34**. These networked classes need not be included in the pre-load class list **26**. If the pre-load analyzer **20** has previously analyzed one or more other applications for the target device **14** then it may take as input a list of classes provided in those applications. The classes already provided in those applications need not be included in the pre-load class list **26**.

The pre-load analyzer **20** generates a pre-load class list **26**. The pre-load class list **26** sets forth a set of pre-load classes **1**-n**3**. The pre-load classes **1**-n**3** are classes needed to support the application program **32** and which are not included in the virtual machine class list **24**. Any one or more of the pre-load classes **1**-n**3** may be subsequently built into the pre-loaded classes **30** of the custom software environment **18**.

FIG. **3** illustrates steps implemented on the pre-load analyzer **20** for generating the pre-load class list **26**. The pre-load analyzer **20** performs the steps **50**-**58** for each of the methods **1**-n**1** of the application program **32**. At step **50**, the pre-load analyzer **20** determines a method to be invoked by the application program **32** when it executes on the target device **14**. The method determined at step **50** is one of the methods **1**-n**1** and may be determined for example by reading a source file associated with the application program **32**.

At step **52**, the pre-load analyzer **20** determines a class associated with the method determined at step **50**. The class may be determined for example by reading class definition files associated with the application program **32**.

At step **54**, the pre-load analyzer **20** writes the class determined at step **52** to the pre-load class list **26** if the class determined at step **52** is not listed in the virtual machine class list **24** or in the pre-load class list **26**. This is because it is not necessary to pre-load the class determined at step **52** if it is one of the native classes **1**-n**2** or if it is already listed as one of the pre-load classes **1**-n**3**.

At step **56**, the pre-load analyzer **20** recursively determines any dependant classes to the class determined at step **52**. For example, the class determined at step **52** may be a subclass of another class which in turn may be a subclass of yet another class. These parent classes etc. are selected at step **56** as classes which depend from the class determined at step **52**. In addition each dependant class may have its own set of dependent classes each of which may have its own set of dependant classes etc. The entire dependence tree is traversed at step **56** to determine the classes which depend from the class determined at step **52**.

At step **58**, for each dependent class determined at step **56**, the pre-load analyzer **20** writes the dependant class to the pre-load class list **26** if the dependant class is not listed in the virtual machine class list **24** or in the pre-load class list **26**. This is because it is not necessary to pre-load the dependant class if it is one of the native classes **1**-n**2** or if it is already listed as one of the pre-load classes **1**-n**3**.

After steps **50**–**58** are completed for each method **1**-n**1** of the application program **32**, the pre-load class list **26** contains the pre-load classes **1**-n**3** which may be included in the pre-loaded classes **30** of the custom software environment **18**. The developer of the custom software environment **18**, i.e. the user of the custom environment tools **16** can optionally specify some of the pre-load classes **1**-n**3** which are not to be included in the pre-loaded classes **30**. For example, one or more of the pre-load classes **1**-n**3** that is seldom invoked or that consumes large amounts of resources in the target device **14** may be excluded from the pre-loaded classes **30** when the custom software environment **18** is built. The excluded ones of the pre-load classes **1**-n**3** may be loaded from a file system or via a network when needed during execution of the application program **32** in the target device **14** depending on the configuration of the target device **14**.

FIG. **4** shows an example arrangement for the custom software environment **18**. The arrangement shown is built by the custom environment tools **16**. The custom software environment tools **16** are used to assemble together the virtual machine **34**, a set of code for each of the pre-load classes **1**-n**3** which were not excluded by user intervention, and a table **60** into the custom software environment **18**. The virtual machine **34** is in one embodiment code native to the target device **14**. The sets of code for the pre-load classes **1**-n**3** are in one embodiment Java byte code. In other embodiment, any one or more of the sets of code for the pre-load classes **1**-n**3** may be in Java byte code or native code for the target device **14**.

The table **60** holds references, such as addresses, to the pre-load classes **1**-n**3** byte code. When the application program **32** invokes a method in one of the pre-load classes **1**-n**3**, the virtual machine **34** obtains the appropriate reference from the table **60** and uses it to reference the appropriate byte code. For example, when the application program **32** invokes a method in the pre-load class **1**, the virtual machine **34** obtains the reference to the pre-load class **1** from the table **60** and uses it to reference the pre-load class 1 byte code. The virtual machine **34** then interprets and executes the referenced byte code.

FIG. **5** shows one embodiment of the target device **14**. The target device **14** is an embedded system which includes a hardware platform **96** for the custom software environment **18** and the application program **32**. The hardware platform **96** includes a processor and related resources such as memory. In this embodiment, the application program **32** is a Java application and the virtual machine **34** in the custom software environment **18** is a Java virtual machine with its native classes **1**-n**2** implemented in native code for the hardware platform **96**.

In this embodiment, the target device **14** includes a set of file system resources **92**. The file system resources **92** represent elements such as magnetic media including rotating media or solid-state devices or other storage mechanisms. The file system resources **92** also represents the appropriate software elements for implementing a file system in the target device **14**. The file system resources **92** may be used to store one or more class libraries.

In this embodiment, the target device **14** also includes a set of network access resources **94**. The network access resources **94** represent the appropriate hardware and software elements that enable communication via a network **100** using the hyper-text transfer protocol (HTTP). The physical communication path support by network access resources **94** may be a communication link such as Ethernet, a wireless communication link including infrared, a radio link including cellular radio, or a serial or parallel communication link depending on the nature and cost constraints associated with the design of the target device **14**.

The virtual machine **34** of the custom software environment **18** includes a class loader **90** which executes appropriate ones of the pre-loaded classes **30** when the application program **32** invokes corresponding ones of the methods **1**-n**1**. As described above, the pre-loaded classes **30** are preselected when the custom software environment **18** is created and built using the custom environment tools **16**. The class loader **90** in this embodiment also loads classes from a class library in the persistent store **92** or from a server **110** via the network **100**.

The server **110** may be an HTTP server which exports one or more Java class libraries. The class loader **90** as part of its configuration is provided with a uniform resource locator (URL) associated with the Java class libraries exported by the server **110**. The class loader **90** loads a class from the server **110** by generating an HTTP GET command to the URL associated with the Java class libraries exported by the server **110** and transferring the HTTP GET command via the network **100**. The server **110** in response transfers the specified files back to the target device **14** and the class loader **90** loads the files into memory for execution by the virtual machine **34**.

FIG. **6** shows steps implemented in the class loader **90** for loading a particular class which is not one of the native classes **1**-n**2**. These steps are undertaken when the application program **32** invokes a method in the particular class. At step **70**, the class loader **90** determines whether the particular class is one of the pre-loaded classes **30**. This may be indicated in the table **60** or another table that identifies individual ones of the pre-loaded classes **30**. If the particular class is one of the pre-loaded classes **30** then at step **72** the class loader **90** obtains a reference to the particular class from the table **60** and executes the referenced byte code in the pre-loaded classes **30**.

If the particular class is not one of the pre-loaded classes **30** then at step **74** the class loader **90** determines whether a class path to a local file system is defined. This may be done using a CLASS PATH definition statement for the virtual machine **34** that specifies a file system pathname for class libraries provided in the target device **14**. If a class path is not defined then the class loader **90** moves to step **78**.

If a class path is defined then the class loader **90** moves to step **76**. At step **76**, if the particular class is found in the specified class libraries then the class loader **90** moves to step **77**. At step **77**, the particular class is loaded from the file system and executed. The particular class loaded from the file system may be in Java byte code or in native code for the hardware platform **96**.

At step **78**, the class loader **90** determines whether the particular class is network classed. In one embodiment, a class is network classed if a NETWORK CLASS PATH definition statement is provided to the virtual machine **34**. The NETWORK CLASS PATH definition statement provides information that enables loading of the class via the network **100**. An example NETWORK CLASS PATH definition statement is as follows.

NETWORK CLASS PATH="network class"

where network class is a URL of a class library which is being exported by the server **110**.

If the particular class is network classed then at step **80**, the class loader **90** loads the particular class via the network **100** to the target device **14** and executes it. For example, at step **80** the class loader **90** issues an HTTP GET command to the URL "network class" to obtain the byte code for the particular class. The code for the particular class obtained from the server **110** may be Java byte code or native code for the hardware platform **96**.

The foregoing detailed description of the present invention is provided for the purposes of illustration and is not intended to be exhaustive or to limit the invention to the precise embodiment disclosed. Accordingly, the scope of the present invention is defined by the appended claims.

What is claimed is:

1. A system for creating a custom software environment which when executed on a target device enables at least one application program to execute on the target device, the system comprising tools that (1) generate a pre-load class list that specifies a set of classes needed to support the application program and (2) build the custom software environment including a set of code for a virtual machine and a set of code for each of a set of pre-load classes specified in the pre-load class list wherein the tools perform the steps of:

determining a method to be invoked by the application program;

determining a class associated with the method;

if the class is not a native class of the virtual machine or is not listed in the pre-load class list then writing the class to the pre-load class list;

determining any dependant classes to the class;

for each dependent class, if the dependant class is not a native class of the virtual machine or is not listed in the pre-load class list then writing the dependent class to the pre-load class list.

2. The system of claim 1, wherein the class and the dependant class are not written to the pre-load class list if listed in a list of networked classes for the custom environment.

3. The system of claim 1, wherein the class and the dependant class are not written to the pre-load class list if listed in a list of classes for one or more other application programs for the target device.

4. The system of claim 1, wherein any one or more of the sets of code for the pre-load classes is Java byte code.

5. The system of claim 1, wherein any one or more of the sets of code for the pre-load classes is native code for the target device.

6. The system of claim 1, wherein the custom environment includes a table that stores a reference to each set of code for the pre-load classes.

7. The system of claim 6, wherein the virtual machine includes a class loader that performs the steps of:

determining whether a class invoked by the application program is one of the pre-load classes;

if the class invoked by the application program is one of the pre-load classes then obtaining the reference to the class invoked by the application program from the table.

8. The system of claim 7, wherein the class loader further performs the steps of:

determining whether the class invoked by the application program is located on a file system in the target device;

if the class invoked by the application program is located on the file system then loading the class invoked by the application program from the file system.

9. The system of claim 7, wherein the class loader further performs the steps of:

determining whether the class invoked by the application program is located on a network server;

if the class invoked by the application program is located on the network server then loading the class invoked by the application program from the network server.

10. The system of claim 9, wherein the step of loading the class invoked by the application program from the network server includes the step of transferring an HTTP GET command to the network server.

11. The system of claim 1, wherein a user excludes one or more of the classes from the pre-load class list from being built into the custom environment.

12. A device, comprising:

a set of processing resources;

application program;

custom software environment which is pre-built for executing the application program, the custom software environment including a set of code for a virtual machine and a set of code for each of a set of pre-load classes which are preselected for execution of the application program wherein the pre-load classes are pre-selected by pre-determining a method to be invoked by the application program and pre-determining a class associated with the method and if the class is not a native class of the virtual machine then pre-selecting the class and any dependant classes to the class wherein the custom software environment includes a table that stores a reference to each of the pre-loaded classes and wherein the custom software environment includes a class loader that performs the steps of:

determining whether a class invoked by the application program is one of the pre-loaded classes;

if the class invoked by the application program is one of the pre-loaded classes then obtaining the reference to the class invoked by the application program from the table.

13. The device of claim 12, further comprising a file system, wherein the class loader further performs the steps of:

determining whether the class invoked by the application program is stored on the file system;

if the class invoked by the application program is stored on the file system then loading the class invoked by the application program from the file system.

14. The device of claim 12, further comprising a set of network access resources wherein the class loader further performs the steps of:

determining whether the class invoked by the application program is located on a network server;

if the class invoked by the application program is located on the network server then loading the class invoked by the application program from the network server using the network access resources.

15. The device of claim 14, wherein the step of loading the class invoked by the application program from the network server includes the step of transferring an HTTP GET command to the network server.

* * * * *